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(54) **WEIGHTED-FAIR-QUEUING RELATIVE BANDWIDTH SHARING**

(75) Inventor: **Erik Andersen**, Mountain View, CA (US)

(73) Assignee: **Broadcom Corporation**, Irvine, CA (US)

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This patent is subject to a terminal disclaimer.

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(52) **U.S. Cl.** **370/235.1**; 370/412; 370/419; 709/233; 709/234

(58) **Field of Classification Search** 370/229, 370/235, 235.1, 351, 389, 395.1, 395.4, 232, 370/395.21, 230.1, 236, 412–419, 429; 398/58; 709/232–234
See application file for complete search history.

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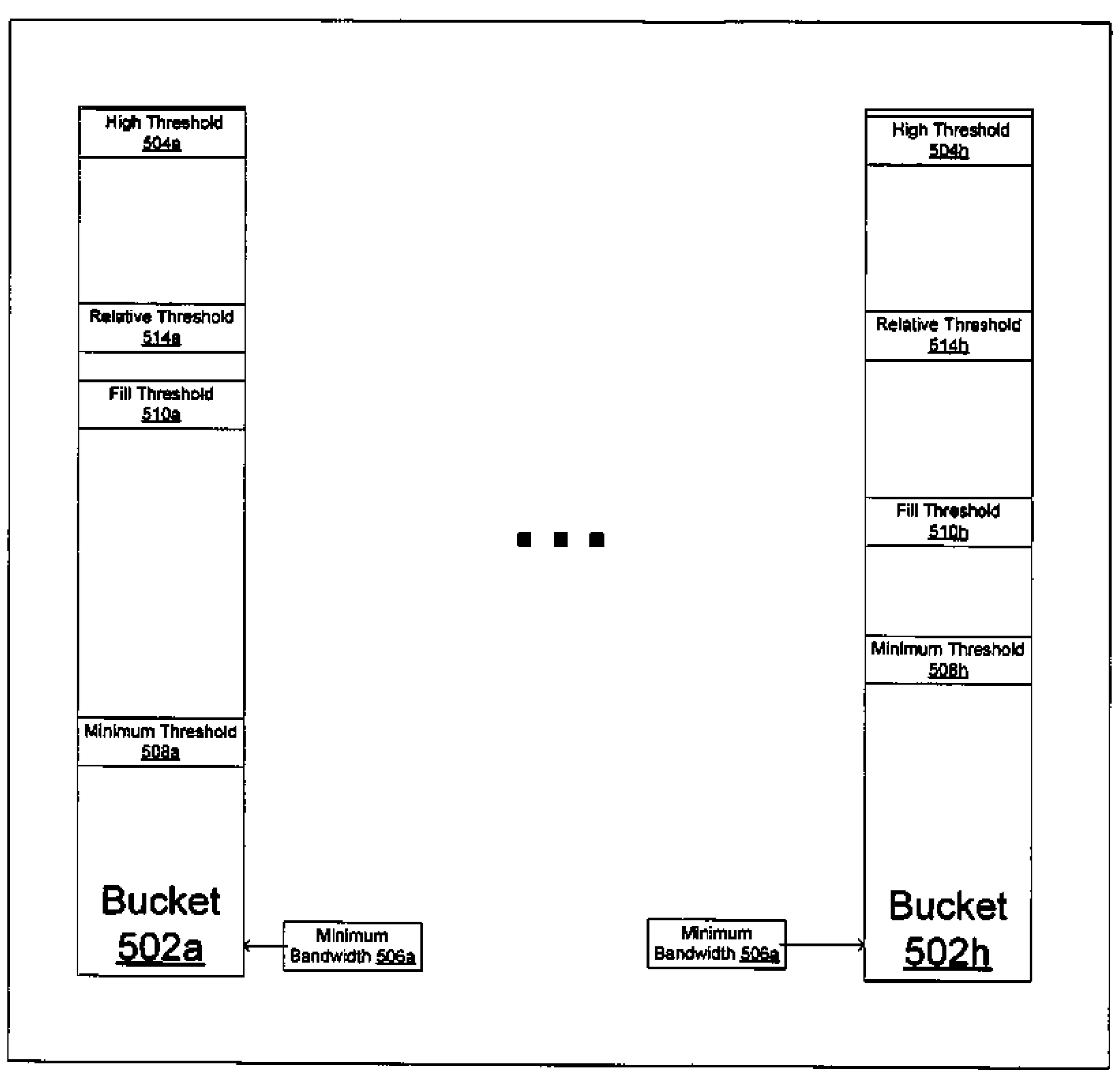
Assistant Examiner — Jeffrey M Rutkowski

(57) **ABSTRACT**

A network device for scheduling packets in a plurality of queues. The network device includes a plurality of configurable mechanisms, each of which is configured to process information in one of a plurality of queues based on a predefined bandwidth. A scheduler services an associated one of the plurality of queues based on the predefined bandwidth. The network device also includes means for tracking whether or not the plurality of queues has exceeded a predefined threshold. If the plurality of queues has exceeded the predefined threshold, a new bandwidth allocation is calculated for each of the plurality of queues. The new bandwidth allocation replaces the predefined bandwidth and is proportional to the predefined bandwidth for each of the plurality of queues.

16 Claims, 6 Drawing Sheets



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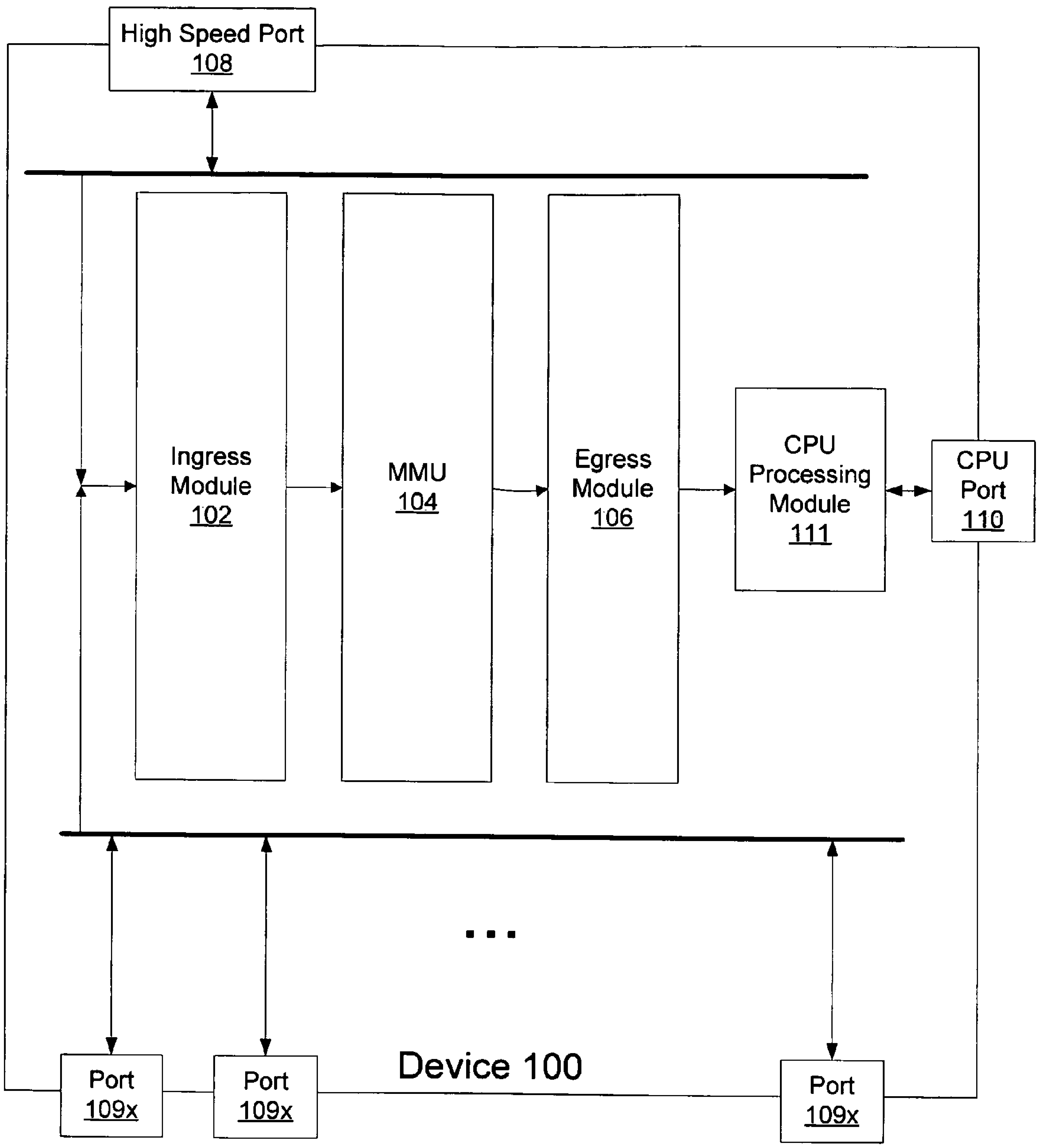

High Speed Port
108
Ingress
Module
102
MMU
104
Egress
Module
106
CPU
Processing
Module
111
CPU
Port
110
...
Device 100
Port
109x
Port
109x
Port
109x

Figure 1

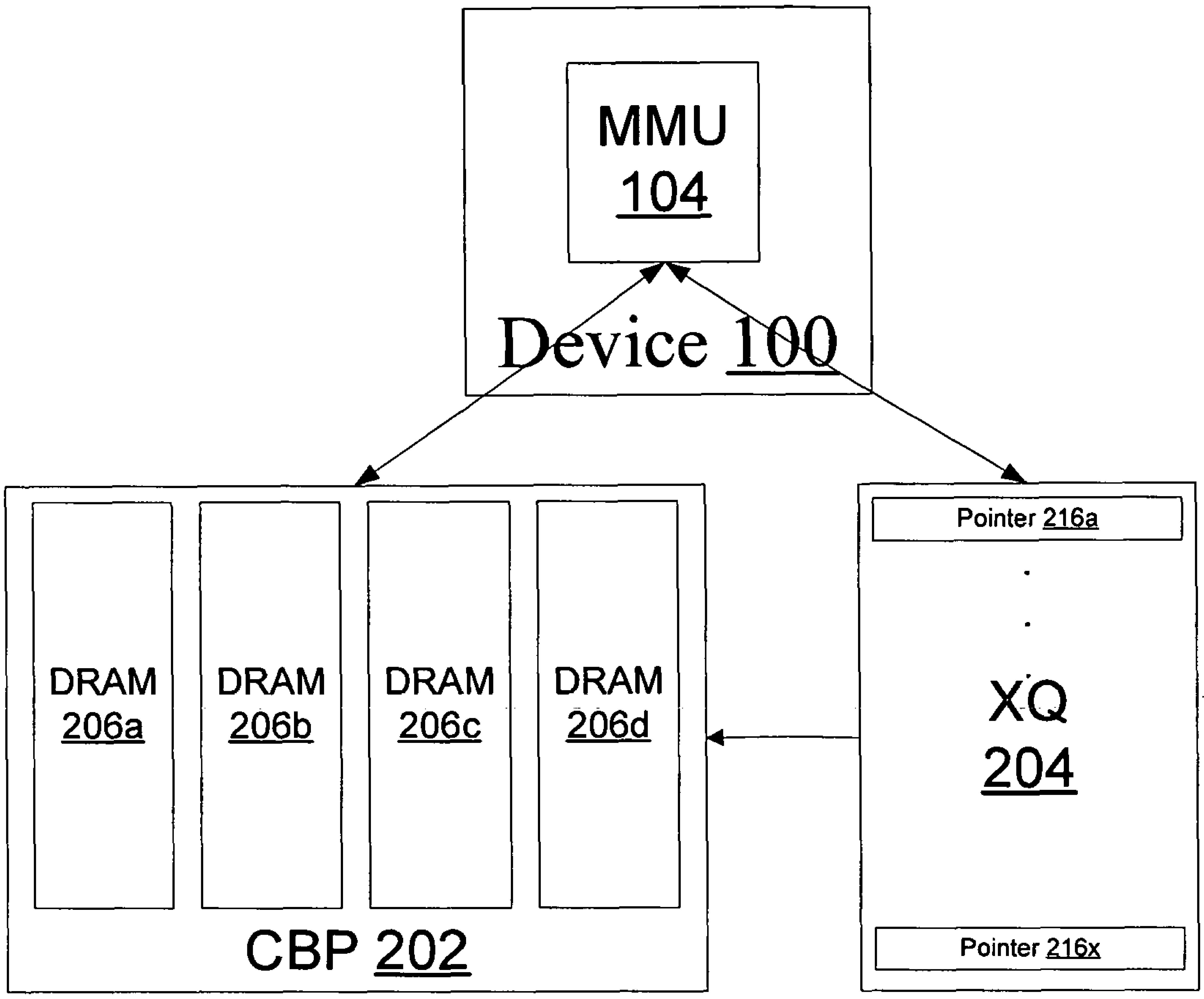


Figure 2a

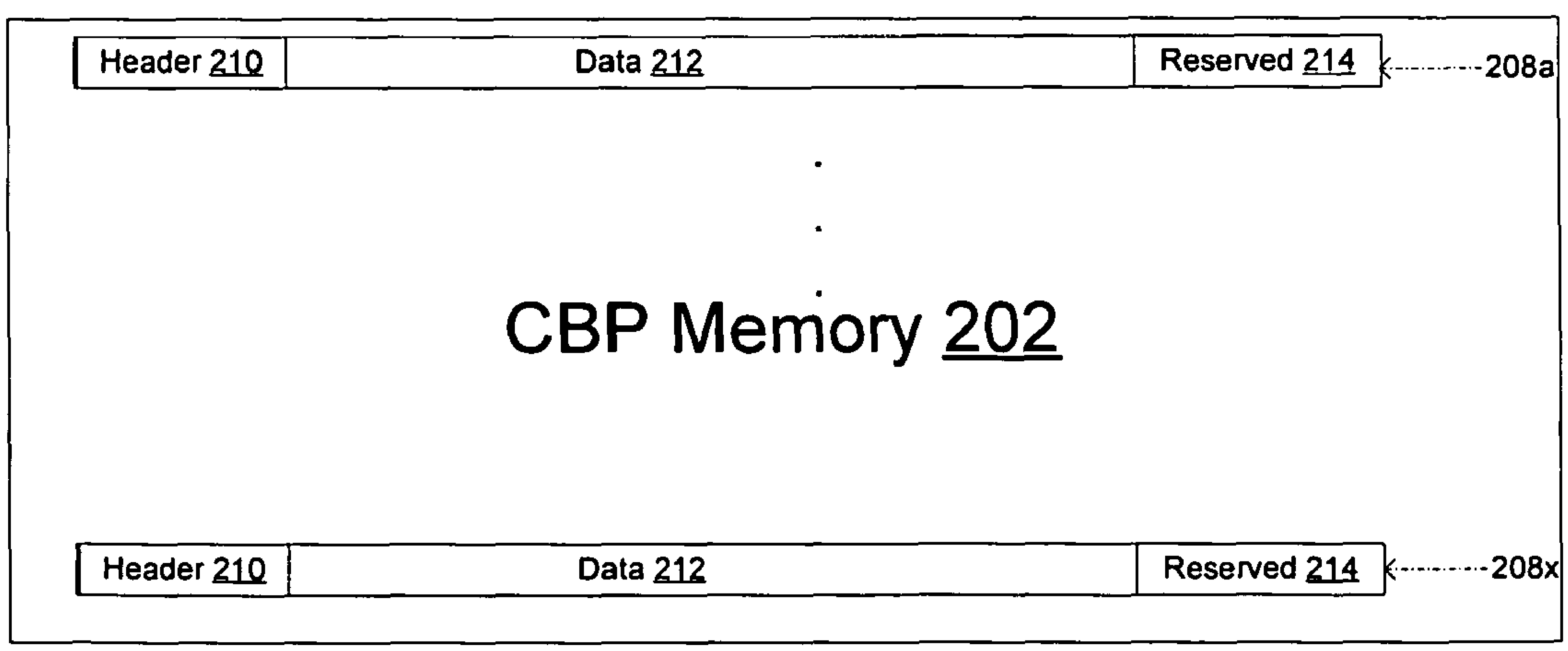
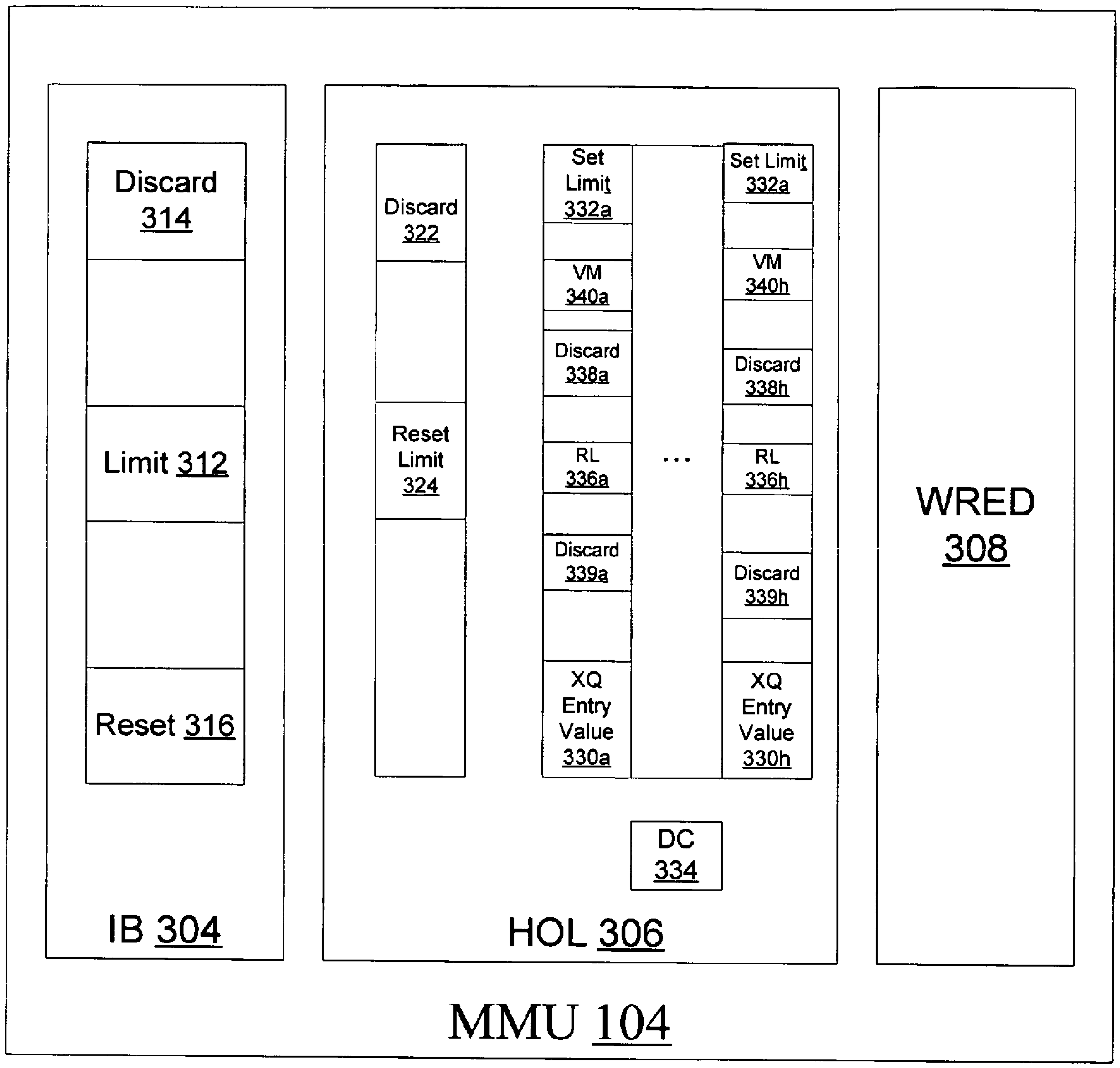


Figure 2b



Discard 314
Limit 312
Reset 316
IB 304
Discard 322
Reset Limit 324
Set Limit 332a
VM 340a
Discard 338a
RL 336a
Discard 339a
XQ Entry Value 330a
...
Set Limit 332a
VM 340h
Discard 338h
RL 336h
Discard 339h
XQ Entry Value 330h
DC 334
HOL 306
WRED 308
MMU 104

Figure 3

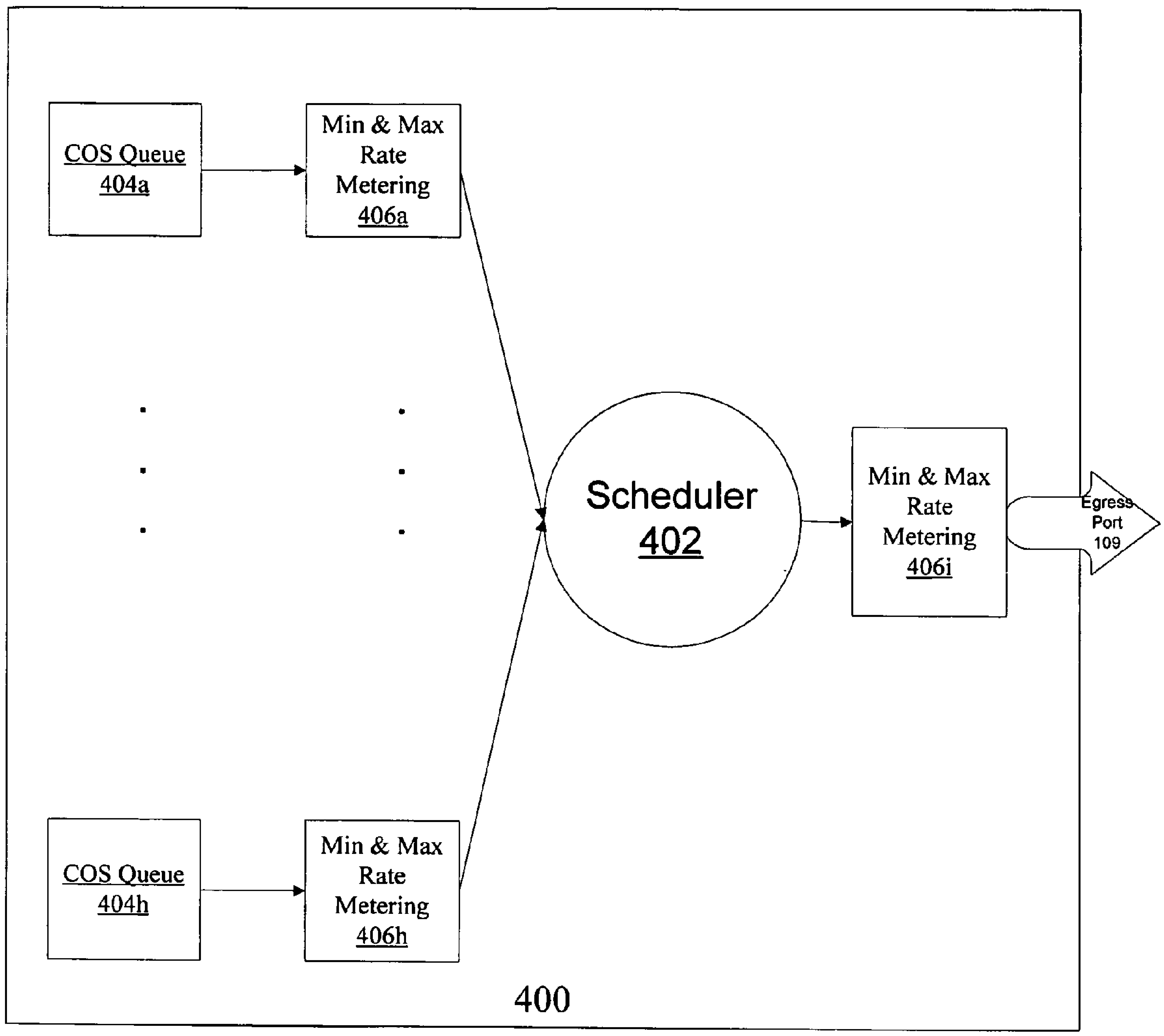
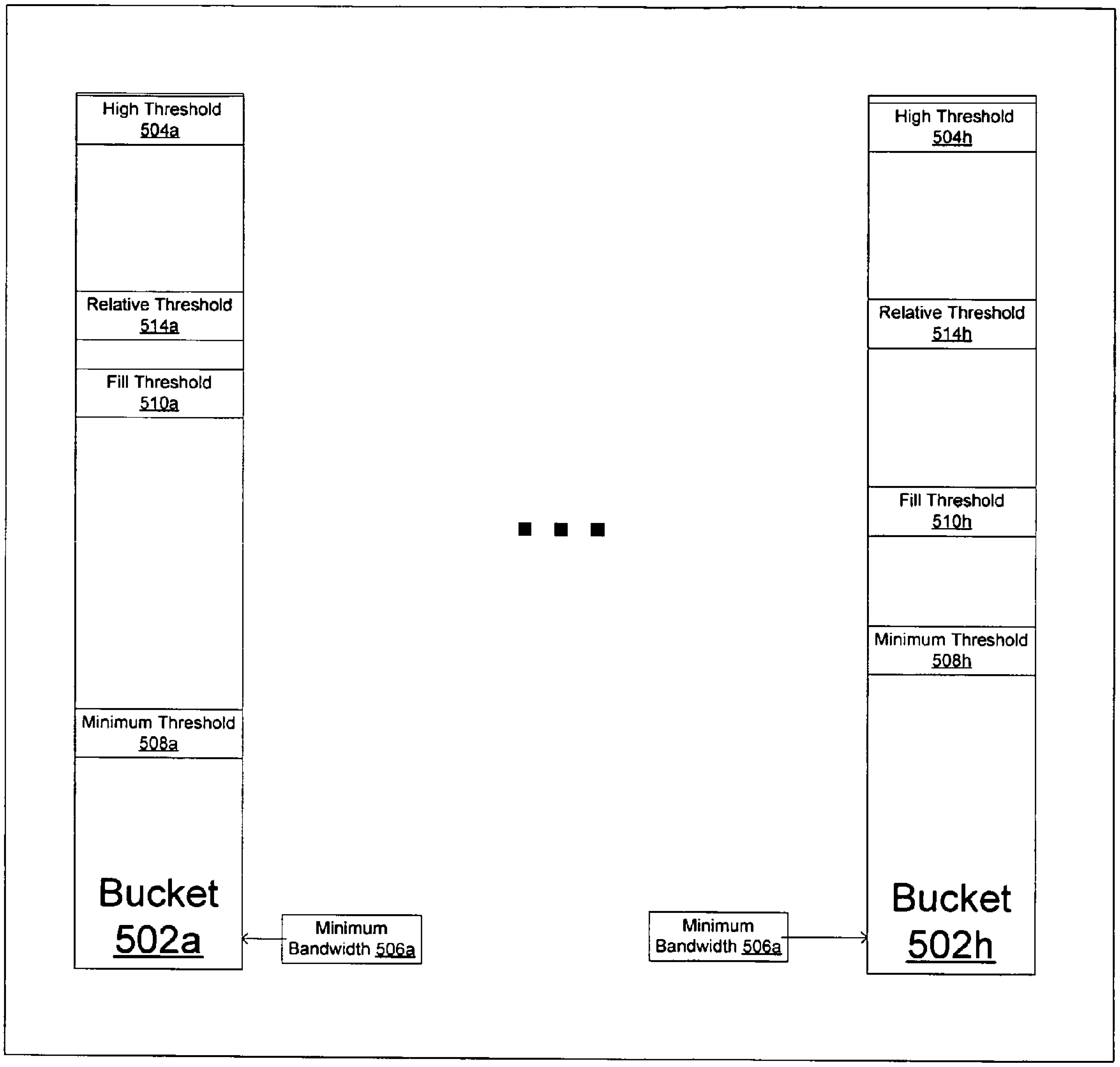

COS Queue
404a
Min & Max
Rate
Metering
406a
Scheduler
402
Min & Max
Rate
Metering
406i
Egress
Port
109
COS Queue
404h
Min & Max
Rate
Metering
406h
400

Figure 4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Relative Threshold 514a
Fill Threshold 510a
Minimum Threshold 508a
Bucket 502a
Minimum Bandwidth 506a
High Threshold 504h
Relative Threshold 514h
Fill Threshold 510h
Minimum Threshold 508h
Minimum Bandwidth 506a
Bucket 502h

Figure 5

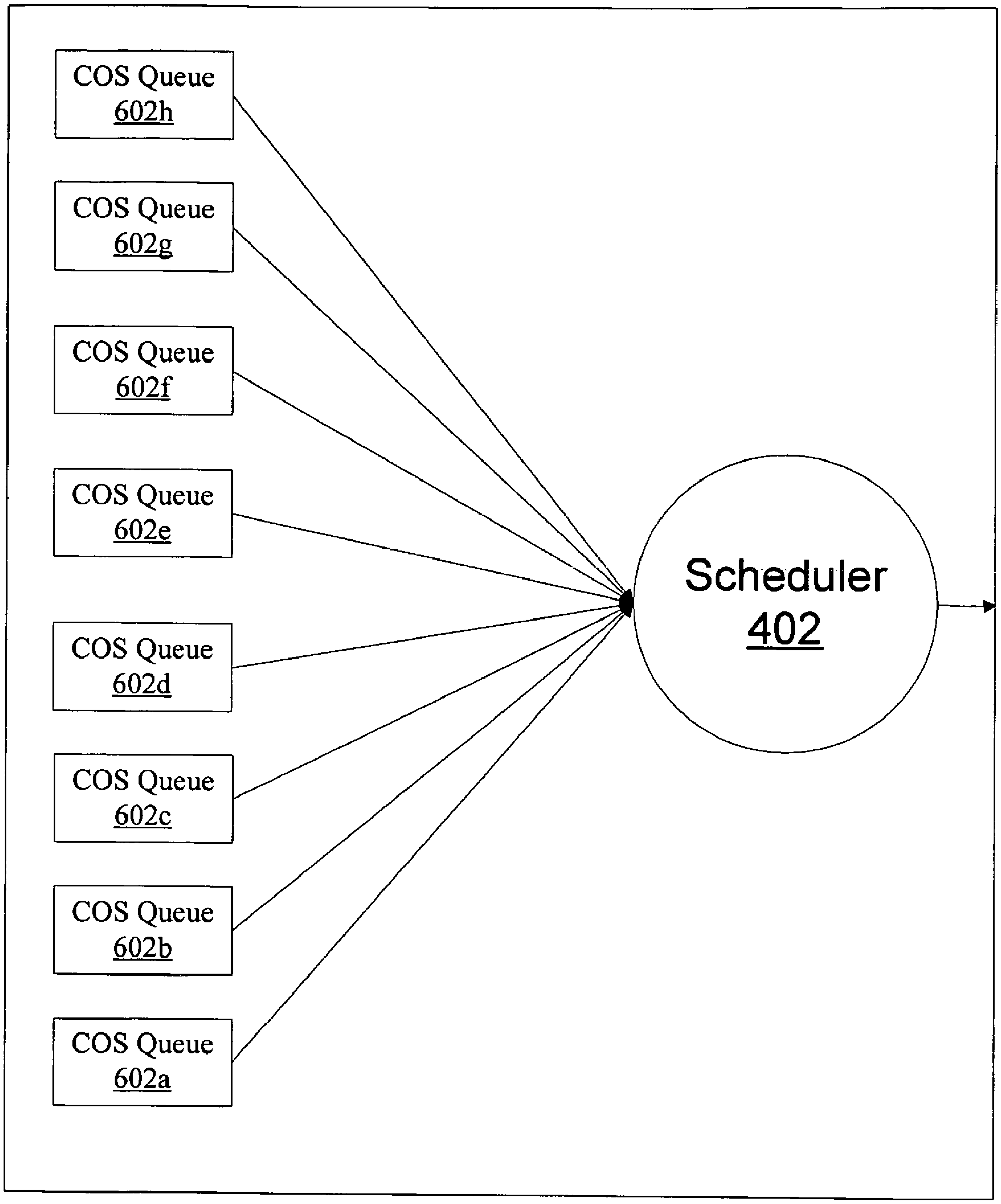
COS Queue
602h
COS Queue
602g
COS Queue
602f
COS Queue
602e
COS Queue
602d
COS Queue
602c
COS Queue
602b
COS Queue
602a
Scheduler
402

Figure 6

WEIGHTED-FAIR-QUEUING RELATIVE BANDWIDTH SHARING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a network device in a packet switched network and more particularly to a method of scheduling packets in multiple queues to guarantee quality of service.

2. Description of the Related Art

A packet switched network may include one or more network devices, such as a Ethernet switching chip, each of which includes several modules that are used to process information that is transmitted through the device. Specifically, the device includes an ingress module, a Memory Management Unit (MMU) and an egress module. The ingress module includes switching functionality for determining to which destination port a packet should be directed. The MMU is used for storing packet information and performing resource checks. The egress module is used for performing packet modification and for transmitting the packet to at least one appropriate destination port. One of the ports on the device may be a CPU port that enables the device to send and receive information to and from external switching/routing control entities or CPUs.

As packets enter the device from multiple ports, they are forwarded to the ingress module where switching and other processing are performed on the packets. Thereafter, the packets are transmitted to one or more destination ports through the MMU and the egress module. The MMU enables sharing of packet buffer among different ports while providing resource guarantees for every ingress port, egress port and class of service queue. According to a current switching system architecture, eight class of service queues are associated with each egress port. To ensure bandwidth guarantees across the ports and queues, the device includes a scheduler that provides arbitration across the class of service queues to ensure minimum and maximum bandwidth guarantees. One implementation for ensuring bandwidth guarantees across the queues associated with each port is to assign a fixed portion of the total bandwidth for the port to each queue. As such, a queue that is associated with a class of service with a high priority may be assigned a greater fixed portion than a queue that is associated with a lower priority class of service. The scheduler then processes packets in each queue, for example in a round robin fashion. This implementation is inflexible. For example, when a queue is idle, the bandwidth assigned to that queue is unused even if another queue requires more bandwidth than the amount allocated to it. As such packets may be dropped on one queue that is exceeding its allocated bandwidth while the bandwidth of an idle queue remains unused.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a network device for scheduling packets in a plurality of queues. The network device includes a plurality of configurable mechanisms, each of which is configured to process information in one of a plurality of queues based on a predefined bandwidth. A scheduler services an associated one of the plurality of queues based on the predefined bandwidth. The network device also includes means for tracking whether or not the plurality of queues has exceeded a predefined threshold. If the plurality of queues has exceeded the predefined threshold, a new bandwidth allocation is calculated for each of the plurality of queues. The new bandwidth allocation replaces the predefined bandwidth and is proportional to the predefined bandwidth for each of the plurality of queues.

According to another aspect of the invention, there is provided a method for scheduling packets in a plurality of queues. The method includes the steps of configuring a plurality of configurable mechanisms to process information in a plurality of queues based on a predefined bandwidth and tracking if the plurality of queues has exceeded a predefined threshold. The method also includes the step of calculating a new bandwidth allocation for each of the plurality of queues if the plurality of queues has exceeded the predefined threshold. The new bandwidth allocation replaces the predefined bandwidth and is proportional to the predefined bandwidth for each of the plurality of queues.

According to another aspect of the invention, there is provided an apparatus for scheduling packets in a plurality of queues. The apparatus includes configuring means for configuring a plurality of configurable mechanisms to process information in a plurality of queues based on a predefined bandwidth. The apparatus also includes tacking means for tracking if the plurality of queues has exceeded a predefined threshold. The apparatus further includes calculating means for calculating a new bandwidth allocation for each of the plurality of queues if the plurality of queues have exceeded the predefined threshold, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of queues.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention that together with the description serve to explain the principles of the invention, wherein:

FIG. **1** illustrates a network device in which an embodiment of the present invention may be implemented;

FIG. **2***a* illustrates the shared memory architecture of the present invention;

FIG. **2***b* illustrates the Cell Buffer Pool of the shared memory architecture;

FIG. **3** illustrates buffer management mechanisms that are used by the memory management unit to impose resource allocation limitations and thereby ensure fair access to resource;

FIG. **4** illustrates a configuration of an egress port arbitration implemented in the present invention;

FIG. **5** illustrates the implementation of the minimum and maximum bandwidth metering mechanisms; and

FIG. **6** illustrates an embodiment in which four queues are serviced according to their minimum bandwidth specifications.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference will now be made to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

FIG. **1** illustrates a network device, such as a switching chip, in which an embodiment the present invention may be implemented. Device **100** includes an ingress module **102**, a MMU **104**, and an egress module **106**. Ingress module **102** is used for performing switching functionality on an incoming packet. The primary function of MMU **104** is to efficiently manage cell buffering and packet pointer resources in a predictable manner even under severe congestion scenarios. Egress module **106** is used for performing packet modification and transmitting the packet to an appropriate destination port.

Device **100** may also include one internal fabric high speed port, for example a HiGig port, **108**, one or more external Ethernet ports **109***a*-**109***x*, and a CPU port **110**. High speed port **108** is used to interconnect various network devices in a system and thus form an internal switching fabric for transporting packets between external source ports and one or more external destination ports. As such, high speed port **108** is not externally visible outside of a system that includes multiple interconnected network devices. CPU port **110** is used to send and receive packets to and from external switching/routing control entities or CPUs. According to an embodiment of the invention, CPU port **110** may be considered as one of external Ethernet ports **109***a*-**109***x*. Device **100** interfaces with external/off-chip CPUs through a CPU processing module **111**, such as a CMIC, which interfaces with a PCI bus that connects device **100** to an external CPU.

Network traffic enters and exits device **100** through external Ethernet ports **109***a*-**109***x*. Specifically, traffic in device **100** is routed from an external Ethernet source port to one or more unique destination Ethernet ports. In one embodiment of the invention, device **100** supports twelve physical Ethernet ports **109**, each of which can operate in 10/100/1000 Mbps speed and one high speed port **108** which operates in either 10 Gbps or 12 Gbps speed.

In an embodiment of the invention, device **100** is built around a shared memory architecture, as shown in FIGS. **2***a*-**2***b* wherein MMU **104** enables sharing of a packet buffer among different ports while providing for resource guarantees for every ingress port, egress port and class of service queue associated with each egress port. FIG. **2***a* illustrates the shared memory architecture of the present invention. Specifically, the memory resources of device **100** include a Cell Buffer Pool (CBP) memory **202** and a Transaction Queue (XQ) memory **204**. CBP memory **202** is an off-chip resource that is made of 4 DRAM chips **206***a*-**206***d*. According to an embodiment of the invention, each DRAM chip has a capacity of 288 Mbits, wherein the total capacity of CBP memory **202** is 122 Mbytes of raw storage. As shown in FIG. **2***b*, CBP memory **202** is divided into 256K 576-byte cells **208***a*-**208***x*, each of which includes a 32 byte header buffer **210**, up to 512 bytes for packet data 212 and 32 bytes of reserved space **214**. As such, each incoming packet consumes at least one full 576 byte cell **208**. Therefore in an example where an incoming includes a 64 byte frame, the incoming packet will have 576 bytes reserved for it even though only 64 bytes of the 576 bytes is used by the frame.

Returning to FIG. **2***a*, XQ memory **204** includes a list of packet pointers **216***a*-**216***x* into CBP memory **202**, wherein different XQ pointers **216** may be associated with each port. A cell count of CBP memory **202** and a packet count of XQ memory **204** is tracked on an ingress port, egress port and class of service basis. As such, device **100** can provide resource guarantees on a cell and/or packet basis.

Once a packet enters device **100** on a source port **109**, the packet is transmitted to ingress module **102** for processing. During processing, packets on each of the ingress and egress ports share system resources **202** and **204**. FIG. **3** illustrates buffer management mechanisms that are used by MMU **104** to impose resource allocation limitations and thereby ensure fair access to resources. MMU **104** includes an ingress backpressure mechanism **304**, a head of line mechanism **306** and a weighted random early detection mechanism **308**. Ingress backpressure mechanism **304** supports lossless behaviour and manages buffer resources fairly across ingress ports. Head of line mechanism **306** supports access to buffering resources while optimizing throughput in the system. Weighted random early detection mechanism **308** improves overall network throughput.

Ingress backpressure mechanism **304** uses packet or cell counters to track the number of packets or cells used on an ingress port basis. Ingress backpressure mechanism **304** includes registers for a set of 8 individually configurable thresholds and registers used to specify which of the 8 thresholds are to be used for every ingress port in the system. The set of thresholds include a limit threshold **312**, a discard limit threshold **314** and a reset limit threshold **316**. If a counter associated with the ingress port packet/cell usage rises above discard limit threshold **314**, packets at the ingress port will be dropped. Based on the counters for tracking the number of cells/packets, a pause flow control is used to stop traffic from arriving on an ingress port that have used more than its fair share of buffering resources, thereby stopping traffic from an offending ingress port and relieving congestion caused by the offending ingress port. Specifically, each ingress port keeps track of whether or not it is in an ingress backpressure state based on ingress backpressure counters relative to the set of thresholds. When the ingress port is in ingress backpressure state, pause flow control frames with a timer value of (0xFFFF) are periodically sent out of that ingress port. When the ingress port is no longer in the ingress backpressure state, the pause flow control frame with a timer value of 0x00 is sent out of the ingress port and traffic is allowed to flow again. If an ingress port is not currently in an ingress backpressure state and the packet counter rises above limit threshold **312**, the status for the ingress port transitions into the ingress backpressure state. If the ingress port is in the ingress backpressure state and the packet counter falls below reset limit threshold **316**, the status for the port will transition out of the backpressure state.

Head of line mechanism **306** is provided to support fair access to buffering resources while optimizing throughput in the system. Head of line mechanism **306** relies on packet dropping to manage buffering resources and improve the overall system throughput. According to an embodiment of the invention, head of line mechanism **306** uses egress counters and predefined thresholds to track buffer usage on a egress port and class of service basis and thereafter makes decisions to drop any newly arriving packets on the ingress ports destined to a particular oversubscribed egress port/class of service queue. Head of line mechanism **306** supports different thresholds depending on the color of the newly arriving packet. Packets may be colored based on metering and marking operations that take place in the ingress module and the MMU acts on these packets differently depending on the color of the packet.

According to an embodiment of the invention, head of line mechanism **306** is configurable and operates independently on every class of service queue and across all ports, including the CPU port. Head of line mechanism **306** uses counters that track XQ memory **204** and CBP memory **202** usage and thresholds that are designed to support a static allocation of CBP memory buffers **202** and dynamic allocation of the available XQ memory buffers **204**. A discard threshold **322** is defined for all cells in CBP memory **202**, regardless of color marking. When the cell counter associated with a port reaches discard threshold **322**, the port is transition to a head of line status. Thereafter, the port may transition out of the head of line status if its cell counter falls below a reset limit threshold **324**.

For the XQ memory **204**, a guaranteed fixed allocation of XQ buffers for each class of service queue is defined by a XQ entry value **330***a*-**330***h*. Each of XQ entry value **330***a*-**330***h* defines how many buffer entries should be reserved for an associated queue. For example, if 100 bytes of XQ memory are assigned to a port, the first four class of service queues associated with XQ entries **330***a*-**330***d* respectively may be assigned the value of 10 bytes and the last four queues associated with XQ entries **330***d*-**330***h* respectively may be assigned the value of 5 bytes. According to an embodiment of the invention, even if a queue does not use up all of the buffer entries reserved for it according to the associated XQ entry value, head of line mechanism **306** may not assign the unused buffer to another queue. Nevertheless, the remaining unassigned 40 bytes of XQ buffers for the port may be shared among all of the class of service queues associated with the port. Limits on how much of the shared pool of the XQ buffer may be consumed by a particular class of service queue is set with a XQ set limit threshold **332**. As such, set limit threshold **332** may be used to define the maximum number of buffers that can be used by one queue and to prevent one queue from using all of the available XQ buffers. To ensure that the sum of XQ entry values **330***a*-**330***h* do not add up to more than the total number of available XQ buffers for the port and to ensure that each class of service queue has access to its quota of XQ buffers as assigned by its entry value **330**, the available pool of XQ buffer for each port is tracked using a port dynamic count register **334**, wherein dynamic count register **334** keeps track of the number of available shared XQ buffers for the port. The initial value of dynamic count register **334** is the total number of XQ buffers associated with the port minus a sum of the number of XQ entry values **320***a*-**320***h*. Dynamic count register **334** is decremented when a class of service queue uses an available XQ buffer after the class of service queue has exceeded its quota as assigned by its XQ entry value **330**. Conversely, dynamic count register **334** is incremented when a class of service queue releases a XQ buffer after the class of service queue has exceeded its quota as assigned by its XQ entry value **330**.

When a queue requests XQ buffer **204**, head of line mechanism **306** determines if all entries used by the queue is less than the XQ entry value **330** for the queue and grants the buffer request if the used entries are less then the XQ entry value **330**. If however, the used entries are greater than the XQ entry value **330** for the queue, head of line mechanism **306** determines if the amount requested is less than the total available buffer or less then the maximum amount set for the queue by the associated set limit threshold **332**. Set limit threshold **332** is in essence a discard threshold that is associated with the queue, regardless of the color marking of the packet. As such, when the packet count associated with the packet reaches set limit threshold **332**, the queue/port enters into a head of line status. When head of line mechanism **306** detects a head of line condition, it sends an update status so that ingress module **102** can drop packets on the congested port. However, due to latency, there may be packets in transition between ingress module **102** and MMU **104** when the status update is sent by head of line mechanism **306**. In this case, the packet drops may occur at MMU **104** due to the head of line status. In an embodiment of the invention, due to the pipeline of packets between ingress module **102** and MMU **104**, the dynamic pool of XQ pointers is reduced by a predefined amount. As such, when the number of available XQ pointers is equal to or less than the predefined amount, the port is transition to the head of line status and an update status is sent to by MMU **104** to ingress module **102**, thereby reducing the number of packets that may be dropped by MMU **104**. To transition out of the head of line status, the XQ packet count for the queue must fall below a reset limit threshold **336**.

It is possible for the XQ counter for a particular class of service queue to not reach set limit threshold **332** and still have its packet dropped if the XQ resources for the port are oversubscribed by the other class of service queues. In an embodiment of the invention, intermediate discard thresholds **338** and **339** may also be defined for packets containing specific color markings, wherein each intermediate discard threshold defines when packets of a particular color should be dropped. For example, intermediate discard threshold **338** may be used to define when packets that are colored yellow should be dropped and intermediate discard threshold **339** may be used to define when packets that are colored red should be dropped. According to an embodiment of the invention, packets may be colored one of green, yellow or red depending on the priority level assigned to the packet. To ensure that packets associated with each color are processed in proportion to the color assignment in each queue, one embodiment of the present invention includes a virtual maximum threshold **340**. Virtual maximum threshold **340** is equal to the number of unassigned and available buffers divided by the sum of the number of queues and the number of currently used buffers. Virtual maximum threshold **340** ensures that the packets associated with each color are processed in a relative proportion. Therefore, if the number of available unassigned buffers is less than the set limit threshold **332** for a particular queue and the queue requests access to all of the available unassigned buffers, head of line mechanism **306** calculates the virtual maximum threshold **340** for the queue and processes a proportional amount of packets associated with each color relative to the defined ratios for each color.

To conserve register space, the XQ thresholds may be expressed in a compressed form, wherein each unit represents a group of XQ entries. The group size is dependent upon the number of XQ buffers that are associated with a particular egress port/class of service queue.

Weighted random early detection mechanism **308** is a queue management mechanism that preemptively drops packets based on a probabilistic algorithm before XQ buffers **204** are exhausted. Weighted random early detection mechanism **308** is therefore used to optimize the overall network throughput. Weighted random early detection mechanism **308** includes an averaging statistic that is used to track each queue length and drop packets based on a drop profile defined for the queue. The drop profile defines a drop probability given a specific average queue-size. According to an embodiment of the invention, weighted random early detection mechanism **308** may defined separate profiles on based on a class of service queue and packet.

FIG. **4** illustrates a configuration of an egress port arbitration implemented in the present invention. According to FIG. **4**, MMU **104** also includes a scheduler **402** that provides arbitration across the eight class of service queues **404***a*-**404***h* associated with each egress port to provide minimum and maximum bandwidth guarantees. Scheduler **402** is integrated with a set of minimum and maximum metering mechanisms **406***a*-**406***i* that monitor traffic flows on a class of service basis and an overall egress port basis. Metering mechanisms **406***a*-**406***i* support traffic shaping functions and guarantee minimum bandwidth specifications on a class of service queue and/or egress port basis, wherein scheduling decisions by schedule **402** are configured largely via traffic shaping mechanisms **406***a*-**406***h* along with a set of control masks that modify how scheduler **402** uses traffic shaping mechanisms **406***a*-**406***h*.

As shown in FIG. **4**, minimum and maximum metering mechanisms **406***a*-**406***i* monitor traffic flows on a class of service queue basis and an overall egress port basis. Maximum and minimum bandwidth meters **406***a*-**406***h* are used to feed state information to scheduler **402** which responds by modifying its service order across class of service queues **404**. The inventive device **100** therefore enables system vendors to implement a quality of service model by configuring class of service queues **404** to support an explicit minimum and maximum bandwidth guarantee. In an embodiment of the invention, metering mechanisms **406***a*-**406***h* monitor traffic flow on a class of service queue basis, provides state information regarding whether or nor a class of service flow is above or below a specified minimum and maximum bandwidth specification, and transmits the information into scheduler **402** which uses the metering information to modify its scheduling decisions. As such, metering mechanisms **406***a*-**406***h* aid in partitioning class of service queues **404** into a set of queues that have not met the minimum bandwidth specification, a set that have met its minimum bandwidth but not its maximum bandwidth specification and a set that have exceeded its maximum bandwidth specification. If a queue is in the set that have not met its minimum bandwidth specification and there are packets in the queue, scheduler **402** services the queue according to the configured scheduling discipline. If a queue is in the set that have met its minimum bandwidth specification but has not exceeded it maximum bandwidth specification and there are packets in the queue, scheduler **402** services the queue according to the configured scheduling discipline. If a queue is in the set that have exceeded its maximum bandwidth specification or if the queue is empty, scheduler **402** does not service the queue.

In an embodiment of the invention, as illustrated in FIG. **5**, minimum and maximum bandwidth metering mechanisms **406***a*-**406***h* are implemented using a simple leaky bucket mechanism which tracks whether or not a class of service queue **404** has consumed its minimum or maximum bandwidth. The range of the minimum and maximum bandwidth setting for each class of service **404** is between 64 kbps to 16 Gbps, in 64 kbps increments. The leaky bucket mechanism has a configurable number of tokens "leaking" out of bucket **502***a*-**502***h*, each of which is associated with one of queues **404***a*-**404***h*, at a configurable rate. In metering the minimum bandwidth for a class of service queue **404**, as packets enter the class of service queue **404**, a number of tokens in proportion to the size of the packet is added to bucket **502**, with a ceiling of bucket high threshold **504**. The leaky bucket mechanism includes a refresh update interface and a minimum bandwidth **506** which defines how many tokens are to be removed every refresh time unit. A minimum threshold **508** is set to indicate whether a flow has satisfied at least its minimum rate and a fill threshold **510** is set to indicate how many tokens are in leaky bucket **502**. When fill threshold **510** rises above minimum threshold **508**, a flag which indicates that the flow has satisfied its minimum bandwidth specification is set to true. When fill threshold **510** falls below minimum threshold **508**, the flag is set to false.

Minimum threshold **508** affects what timescale the minimum bandwidth metering mechanism **406** is required to operate. If the minimum threshold **508** is set at a very low level, class of service queue **404** will quickly flag that its minimum bandwidth has been met. This reduces the amount of time queue **404** is classified in the set of queues that have not met the minimum bandwidth requirement and reduces the time period that the queue is given preferential treatment from scheduler **402**. High threshold **504** affects how much credit can be built up after a class of service queue meets it minimum bandwidth **506**. A large high threshold **504** may result in a reduction of time that the queue is classified with the set of queues that have not met the minimum bandwidth requirement and reduces the time period that the queue is given preferential treatment from scheduler **402**.

After metering mechanisms **406***a*-**406***h* indicate that the maximum bandwidth specified has been exceeded high threshold **504**, scheduler **402** ceases to service the queue and the queue is classified as being in the set of queues that have exceeded it maximum bandwidth specification. A flag is then set to indicate that the queue has exceeded its maximum bandwidth. Thereafter, the queue will only receive service from scheduler **402** when its fill threshold **510** falls below high threshold **504** and the flag indicating that it has exceeded its maximum bandwidth is reset. Metering mechanism **406***i* is used to indicate that the maximum bandwidth specified for a port has been exceeded and operates in the same manner as meter mechanisms **406***a*-**406***h* when the maximum bandwidth has been exceeded. According to an embodiment of the invention, the maximum metering mechanism on a queue and port basis generally affects whether or not queue **404** or a port is to be included in scheduling arbitration. As such, the maximum metering mechanism only has a traffic limiting effect on scheduler **402**.

On the other hand, minimum metering on a class of service queue **404** basis has a more complex interaction with scheduler **402**. In one embodiment of the invention, scheduler **402** is configured to support a variety of scheduling disciplines that mimic the bandwidth sharing capabilities of a weighted fair queuing scheme. The weighted fair queue scheme is a weighted version of packet based fair queuing scheme, which is defined as a method for providing "bit-based round robin" scheduling of packets. As such, packets are scheduled for access to an egress port based on their delivery time, which is computed as if the scheduler is capable of providing bit-based round robin service. A relative weight field influences the specifics of how the scheduler makes use of the minimum metering mechanism, wherein the scheduler attempts to provide a minimum bandwidth guarantee. In an embodiment of the invention, the minimum bandwidth guarantee is a relative bandwidth guarantee wherein a relative field determines whether or not scheduler **402** will treat the minimum bandwidth metering settings as a specification for a relative or an absolute bandwidth guarantee. If the relative field is set, the scheduler treats minimum bandwidth **506** setting as a relative bandwidth specification. Scheduler **402** then attempts to provide relative bandwidth sharing across backlogged queues **404**.

FIG. **6** illustrates an embodiment in which four queues are serviced according to their minimum bandwidth specifications. According to FIG. **6**, a 1 GE egress port has scheduler **402** configured to be in a weighted fair queue mode and has its relative field set to true, wherein the minimum bandwidth for queue **602***a* and **602***b* is 10 Mbps, for queue **602***c* is 20 Mbps and for queue **602***d* is 40 Mbps. If all queues **602** have packets to be serviced, then scheduler **402** will provide relative bandwidth sharing across the active queues according to the predefined minimum bandwidth for each queue. However, since as mentioned above only queues **602***a*-**602***d* have packets to be serviced, queue **602***d* will receive twice the bandwidth of queue **602***c* which receives twice the bandwidth that is given to queues **602***a* and **602***b*. If queues **602***a*-**602***d* have enough packets to keep the 1 GE link fully utilized, queue **602***d* will be allowed to process 500 Mbps, queue **602***c* will be allowed to process 250 Mbps and queues **602***a* and **602***b* will be allowed to process 125 Mbps. On the other hand, if only queues **602***b*-**602***d* are active, the bandwidth distribution will change to appropriately provide relative bandwidth sharing, wherein queue **602***d* will be allowed to process 571.4 Mbps, queue **602***c* will be allowed to process 265.7 Mbps and queue **602***b* will be allowed to process 142.9 Mbps. As such, minimum bandwidth metering mechanisms **406** are constantly being adjusted to achieve the relative bandwidth sharing.

Returning to FIG. **5**, according to an embodiment of the invention, in addition to the relative field, a relative threshold **514** is also set in each of queues **404**. Relative threshold **514** is used to indicate that the minimum bandwidth **506** is set too low when fill threshold **510** of all queues have exceeded relative threshold **514**. As such, when fill threshold **510** for each of queues **404***a*-**404***h* rises above relative threshold **514**, device **100** calculates a new minimum bandwidth **506**, wherein:

$$\text{new minimum bandwidth} = \text{old minimum bandwidth} \ll (K - MSB.POS)$$

wherein K is equal to a constant, and

MSB.POS is equal to a position of the Most Significant Bit

The new minimum bandwidth therefore allows device **100** to leak more tokens out of bucket **502** for each of queues **404***a*-**404***h*, wherein the new leak is proportional to the old leak. According to another embodiment of the invention, the new minimum bandwidth may be calculated for an individual queue when fill threshold for that queue rises above relative threshold **514** for that queue.

The foregoing description has been directed to specific embodiments of this invention. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

What is claimed:

1. A network device for scheduling packets in a plurality of queues, the network device comprising:

means for processing information in one of a plurality of queues based on a predefined bandwidth, wherein a scheduler services an associated one of the plurality of queues based on the predefined bandwidth; and

means for tracking whether or not a plurality of active queues of the plurality of queues has exceeded a predefined threshold, the predefined threshold being used to indicate that the predefined bandwidth for each of the plurality of active queues is set too low when a fill threshold associated with each of the plurality of active queues exceeds the predefined threshold,

wherein only if the fill threshold of all of the plurality of active queues have exceeded the predefined threshold, a new bandwidth allocation is calculated for each of the plurality of active queues, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of active queues.

2. The network device according to claim **1**, wherein the processing means performs leaky bucket algorithms with each of the plurality of active queues.

3. The network device according to claim **1**, wherein the processing means further performs accepting a number of tokens in proportion to the size of a packet being added to the associated queue.

4. The network device according to claim **1**, the processing means use the predefined bandwidth to determine how many tokens to release at predetermined time intervals.

5. The network device according to claim **1**, wherein the means for processing comprises a plurality of thresholds for indicating predefined points in the means for processing.

6. The network device according to claim **1**, wherein the means for tracking is configured to compare a fill rate in each of the plurality of active queues with the predefined threshold to determine if each of the plurality of active queues have exceeded the predefined threshold.

7. The network device according to claim **1**, wherein the scheduler is further configured to process each of the plurality of active queues according to a relative weight field, wherein the relative weight field determines if the predefined bandwidth for each of the plurality of active queues is a relative bandwidth guarantee or an absolute bandwidth guarantee.

8. A network device for scheduling packets in a plurality of queues, the network device comprising:

means for processing information in one of a plurality of queues based on a predefined bandwidth, wherein a scheduler services an associated one of the plurality of queues based on the predefined bandwidth; and

means for tracking whether or not a plurality of active queues of the plurality of queues has exceeded a predefined threshold,

wherein if the plurality of active queues has exceeded the predefined threshold, a new bandwidth allocation is calculated for each of the plurality of active queues, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of active queues,

wherein the means for tracking is configured to calculate the new bandwidth allocation for each of the plurality of active queues as the predefined bandwidth left shifted with the difference of a constant and the position of a most significant bit.

9. A method for scheduling packets in a plurality of queues, the method comprising the steps of:

processing information in a plurality of queues based on a predefined bandwidth using a network device;

tracking if a plurality of active queues of the plurality of queues has exceeded a predefined threshold, the predefined threshold being used to indicate that the predefined bandwidth for each of the plurality of active queues is set too low when a fill threshold associated with each of the plurality of active queues exceeds the predefined threshold; and

calculating a new bandwidth allocation for each of the plurality of active queues only if the fill threshold of all of the plurality of active queues have exceeded the predefined threshold, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of active queues.

10. The method according to claim **9**, further comprising a leaky bucket algorithm with each of the plurality of active queues.

11. The method according to claim **9**, further comprising a number of tokens in proportion to the size of a packet being added to an associated queue.

12. The method according to claim **9**, further comprising using the predefined bandwidth to determine how many token to release at predetermined time intervals.

13. The method according to claim **9**, further comprising comparing a fill rate in each of the plurality of active queues with the predefined threshold to determine if each of the plurality of active queues have exceeded the predefined threshold.

14. The method according to claim 9, further comprising processing each of the plurality of active queues according to a relative weight field, wherein the relative weight field determines if the predefined bandwidth for each of the plurality of active queues is a relative bandwidth guarantee or an absolute bandwidth guarantee.

15. A method for scheduling packets in a plurality of queues, the method comprising the steps of:

processing information in a plurality of queues based on a predefined bandwidth using a network device;

tracking if a plurality of active queues of the plurality of queues has exceeded a predefined threshold;

calculating a new bandwidth allocation for each of the plurality of active queues if the plurality of active queues has exceeded the predefined threshold, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of active queues; and

calculating the new bandwidth allocation for each of the plurality of active queues as the predefined bandwidth left shifted with the difference of a constant and the position of a most significant bit.

16. An apparatus for scheduling packets in a plurality of queues, the apparatus comprising:

configuring means for configuring information to be processed in a plurality of queues based on a predefined bandwidth;

tracking means for tracking if a plurality of active queues of the plurality of queues has exceeded a predefined threshold, the predefined threshold being used to indicate that the predefined bandwidth for each of the plurality of active queues is set too low when a fill threshold associated with each of the plurality of active queues exceeds the predefined threshold; and

calculating means for calculating a new bandwidth allocation for each of the plurality of active queues only if the fill threshold of all of the plurality of active queues have exceeded the predefined threshold, the new bandwidth allocation replacing the predefined bandwidth and being proportional to the predefined bandwidth for each of the plurality of active queues.

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